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Death Valley Springs Geochemical Investigation

Yucca Mountain Nuclear Repository, Inyo County Oversight-1998

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DEATH VALLEY SPRINGS GEOCHMICAL INVESTIGATION

YUCCA MOUNTAIN NUCLEAR WASTE REPOSITORY, INYO COUNTY OVERSIGHT-1998

EXECUTIVE SUMMARY

Yucca Mountain, Nevada is under study as the site of the only proposed high-level nuclear waste repository in the United States. The repository concept uses the philosophy of multiple barriers, both engineered and natural, each of which impedes the movement of radionuclides into the accessible environment. The proposed repository would be in the unsaturated zone in Tertiary tuffaceous rocks. The principal transporting mechanism for radionuclides is moving ground water. Underlying the repository is an extensive Lower Carbonate Aquifer known to be highly permeable. Inyo County, as an affected unit of local government under the Nuclear Waste Policy Act, as amended, is concerned with the connections between the Lower Carbonate Aquifer underlying Yucca Mountain and the carbonate sources of waters in Inyo County, especially the Death Valley region. This report is a summary of the investigations conducted by Inyo County's consultants, the Hydrodynamics Group, during calendar year 1998.

This report presents the results of The Hydrodynamics Group's 1998 collection of water samples from 23 springs and 2 creeks in Death Valley. The overall goal of this study was the evaluation of far-field issues related to potential transport, by ground water, of radionuclides into Inyo County, including Death Valley, and the evaluation of a connection between the Lower Carbonate Aquifer and the biosphere. Death Valley is believed to be a discharge point for regional ground water aquifers below Yucca Mountain. The objective of this geochemical study of spring waters was to help further characterize the ground water in the Death Valley mountain blocks, and to determine the source of these waters.

Prior research was reviewed to determine areas where sampling was needed. Less than 10 percent of known springs in Death Valley National Park have been sampled and analyzed. The sampling of springs for isotopic analysis by the USGS has been limited to the large Funeral Mountain springs discharging along the Furnace Creek Fault and along the alluvial fans on the east flank of the Panamint Mountain range. The USGS had also sampled a select number of springs in the Black Mountain range for isotopic analysis. Following this review the selected water sources were sampled. The samples were collected, preserved, and shipped for analysis to the USGS's Denver laboratory, Huffman Laboratories, and Beta Analytical Laboratory by The Hydrodynamics Group's personnel. The evaluation of the geochemical composition of the springs of the Death Valley National Park and the Yucca Mountain study area established the chemical composition of the spring waters. The comparison of the regional geochemical composition, concentration of isotopes, and the regional geological conditions allowed an evaluation of the source of the spring waters relative to the Lower Carbonate Aquifer.

The results of this study suggest the need to further characterize the springs and hydrogeology of the Death Valley area, and to better understand the hydraulic connection between the Funeral Mountain springs and the Lower Carbonate Aquifer beneath Yucca Mountain and the Amargosa Valley. It is recommended that additional springs be sampled and analyzed for major anion and cations, and stable isotope concentrations. The report further recommends the drilling of two exploratory wells east of the Funeral Mountains to further evaluate the possible hydraulic connection between the springs in the Furnace Creek area and the Lower Carbonate Aquifer.

1.0 INTRODUCTION

Yucca Mountain is the site of the only proposed high-level nuclear waste repository in the United States. The repository concept uses the philosophy of multiple barriers, both engineered and natural, each of which impedes the movement of radionulcides into the accessible environment. The proposed repository would be in the unsaturated zone above the water table in Tertiary tuffaceous rocks. The principal transporting mechanism for radionuclides is moving ground water. Underlying the repository at approximately 2-km (6,000 feet) is an extensive Lower Carbonate Aquifer known to be highly permeable.

Inyo County has participated in oversight activities for the Yucca Mountain Nuclear Waste Repository since 1987. The purpose of Inyo County's oversight activities is to ensure that repository siting and subsequent repository activities do not adversely impact the public health, safety, or welfare of County residents or the environment, including Death Valley National Park. The Hydrodynamics Group, Inyo County's hydrogeology consultants, determined that a linkage between the alluvial and carbonate aquifers at Yucca Mountain and Death Valley in Inyo County may be possible. Winograde (1975) suggested that the springs on the east side of Death Valley may be points of discharge from the Lower Carbonate Aquifer.

This investigation of Death Valley springs was performed in support of Inyo County's Yucca Mountain Oversight Program. Inyo County's Yucca Mountain Oversight Program identified a number of spring sources in the Death Valley Mountain ranges. This report presents the results of The Hydrodynamics Group's 1998 collection of water samples from 23 springs and 2 creeks in Death Valley. Samples were analyzed for concentrations of major cations and anions, and isotopic ratios of strontium, uranium, and oxygen. The results of the analysis were compared to the chemical analyses of other available carbonate aquifer and spring samples in the Yucca Mountain project area.

1.1 Statement of the Problem

The linkages between the alluvial and carbonate aquifers, the recharge and discharge points, and ground water travel time are key to Inyo County's hydrological concerns about the proposed Yucca Mountain Nuclear Waste Repository. Death Valley is the terminus for surface water drainage from Yucca Mountain and Amargosa Valley. It is also believed that ground water from the Lower Carbonate Aquifer discharges into Death Valley via springs. The relationship between waters in Death Valley and the ground water flowing under Yucca Mountain has yet to be determined.

Specifically, The Hydrodynamics Group's hydraulic model (Bredehoeft, et. al., 1996) of the Amargosa River system indicates a negative water balance. Measured stream flows exceed what would be expected for published evapotranspiration (ET) rates and precipitation. This suggests a significant contribution to Amargosa river flows from a larger ground water system (Bredehoeft, et. al., 1996). Winograd (1975) and other researchers suggest that ground water in the Yucca Mountain area is hydraulically connected to the Lower Carbonate Aquifer. Discharge from the major springs in Death Valley may be fault-controlled and hydraulically connected to the Lower Carbonate Aquifer.

The U.S. Geological Survey's (USGS) numerical ground water model of the Yucca Mountain area (D'Agnesses, et. al., 1997) is based on limited data on the hydrology of the Death Valley system. Major data gaps exist in:

1. ET values for Death Valley,
2. inflow into Death Valley from the Amargosa River,
3. infiltration into the Death Valley mountain ranges,
4. the source of spring waters in Death Valley,
5. water level data,
6. hydraulic parameters, and
7. hydraulic boundary conditions in Death Valley.

These major data gaps need to be filled for the USGS numerical ground water model of the Yucca Mountain area to be used effectively as a tool to evaluate the potential for the transport of radionuclides from Yucca Mountain.

The drilling of wells in Death Valley is environmentally unacceptable. The chemical analysis of spring and creek waters in Death Valley provides an environmentally acceptable means of evaluating the source of these waters. Ground water can absorb and precipitate chemicals from rock materials along its flow path. The dissolved chemicals in the waters can also react to produce compounds or ratios of selected chemicals that suggest either a source for the water or a travel path for the water. A limitation on use of chemical analysis for water source analysis is that the interpretation of results does not provide a definitive answer. This is partially due to the possible mixing of waters from more than one source. Thus, the interpretation of chemical composition of waters for purposes of source analysis can be problematic.

1.2 Goal and Objective

The overall goal of this study was the evaluation of far-field issues related to potential transport, by ground water, of radionuclides into Inyo County, including Death Valley, and the evaluation of a connection between the Lower Carbonate Aquifer and the biosphere. Death Valley is believed to be a discharge point for regional ground water aquifers below Yucca Mountain.

The objective of this geochemical study of spring waters was to help further characterize the ground water in the Death Valley mountain blocks, and to determine the source of these waters.

2.0 Hydrogeology of the Death Valley Drainage Basin

The hydrogeology of the Death Valley Drainage Basin is important to the understanding of the movement of ground water from Yucca Mountain and the spring discharge in Death Valley National Park (DVNP). Please note that while reference will be made to Death Valley Natiional Monument (DVNM), the springs sampled for this study are within the original boundaries of the DVNM. The National Monument was changed to a National Park by the California Desert Protection Act of 1992, with the addition of 1.3 million acres to the lands formerly designated as a National Monument. The boundary of the Park,, while approximately fixed in 1994, are not yet generally available in map form. The geology of the Death Valley Drainage Basin (DVDB) and the hydrostratigraphy of Death Valley are described below. This provides a framework for the characterization of springs in Death Valley.

2.1 Geologic Framework of the Death Valley Drainage Basin

The geology and hydrogeology of the DVDB, which includes DVNP, has been described in countless books, publications, and articles. Among these are Charles Hunt's book entitled *Death Valley: Geology, Ecology, Archaeology*, 1975; and Harris & Tuttle's book entitled *Geology of National Parks*, Fifth Edition, 1997. More recently, Harrill (1995), Faunt (1997), and D'Agnese, et. al., (1997) published articles on the geology and hydrogeology of the DVDB. The USGS publications were specific to issues concerning the modeling of ground water within the Yucca Mountain nuclear waste repository study area. An overview of the geology and hydrogeology of the DVDB and DVNP, as presented by these and other authors is provided below.

Death Valley is located in the southwest corner of the Great Basin physiographic province and in the southwest portion of the DVDB (Plate 1). The Great Basin and DVDB are within the northern part of the Basin and Range physiographic province. Numerous northwest-trending mountain ranges and intervening broad and flat valleys, or basins, characterize the Basin and Range province. The ranges are spaced about 20-30 km (12 to 18 miles) apart.

The DVDB covers an area of about 40,100 km^2 (15,800 $mi.^2$). Surface and ground water drainage in the Basin is, in general, towards Death Valley. The DVDB includes the northwest trending basins and ranges of the Panamint Valley, Panamint Range, Death Valley, Grapevine-Funeral-Black Mountain Ranges, Amargosa Valley, and Yucca-Spector-Spring Mountain Range (Plate 2). The mountain ranges cover about 25 percent of DVDB, and can be greater then 80 km (50 miles) in length, and 8 to 24 km (5 to 15 miles) wide (Herrill, 1995). The altitude of these ranges varies between 304 to 2,743 meters (1,000 to 9,000 feet) above valley floors. The intervening basin can extend over 120 km (75 miles) in length, and can range in width from 3 to 40 km (2 to 25 miles). The valley floors are relatively flat with altitudes ranging from 5,000 feet in the northern half of the DVDB to over –60 meters (-200 feet) in Death Valley.

The Death Valley portion of the Great Basin has a long geological history. Mifflin (1988) states that:

> *The Great Basin region displays the record of a long and active history of intermittent marine sedimentation and large-scale compressive deformation, island-arc plutonism and volcanism, bimodal basaltic and silicic volcanism, extensional tectonics, and terrestrial sedimentation.* Mifflin further states: *Rock types, ages, and deformational structures range through much of the known spectrum, and in many areas impressive diversities exist in juxtaposed rock types.*

This results in geology that is highly variable and complex. Although it is possible to readily map the surface geology of the area, our knowledge of the subsurface geology beneath the alluvial basin is based upon a limited number of boreholes. The areal distribution of major geological rock types in the DVDB is shown on Plate 3. Faunt (1997) states the DVDB consists of:

> *Precambrian- and Cambrian-age clastic and crystalline rocks: Paleozoic-age clastic and carbonate rocks; clastic and intrusive rocks of Mesozoic age; varied fluvaial, paludal,*

pond, and playa sedimentary rocks of Pliocene age; volcanic rocks and alluvium of Tertiary age; and alluvium, colluvium, and eolian deposits of Quaternary age.

A generalized geologic column of major geological rock types is provided in Table 1. Fiero (1986) illustrated the geological history of the Great Basin, which includes the DVNP, in his book entitled *Geology of the Great Basin, 1986.* A summary of the principal geologic events in DVNP as discussed in Fiero's book is listed in Table 1. It is evident that a variety of sedimentary and igneous intrusive and extrusive rocks have been subjected to both compressional and extensional deformation (Harrell, 1995). Compressional and extensional deformation activities are evident in the complex patterns of high and low angle faults, which have been mapped by Faunt (D'Agnesse, et al, 1997) (Plate 4). Currently Death Valley is experiencing extensional deformation and tilting to the east resulting in the continued dropping of Death Valley.

2.2 Hydrogeology Framework of DVDB

Pal Consultants' report entitled *A Conceptual Model of the Death Valley Ground-Water Flow System, Nevada, California, 1995,* (Harrell, 1995) provides an extensive presentation on the numerous published studies that developed conceptual models of the hydrogeology framework of Death Valley. Central to the recently developed hydrogeology framework models of the DVDB is the integration of hydrostratigraphic units and structural elements.

In an idealized basin and range setting, ground water generally moves downward from mountainous recharge regions, then laterally toward discharge areas, and then upward into the discharge areas (Faunt, 1997). Faunt (1997) states that:

The mountain ranges consist primarily of uplifted, faulted, and exhumed rocks of metamorphic and sedimentary origin. Locally, the rocks have been intruded or overlain by both volcanic and intrusive rocks of many different ages and compositions. The way in which these rocks were deposited, lithified, deformed, fractured, and weathered ultimately controls the way in which ground water enters, flows through, and exits the hydrogeologic system.

Death Valley is the terminal discharge point for 27 hydrographic areas, with a surface area of about 40,922 km^2 (15,800 $mi.^2$), (Plate 5) (Harrel, 1995). Faunt (1997) defined the hydrogeologic framework of these hydrographic areas by use of hydrostratigraphic map units (Plate 6). The hydrostratigraphic map of DVDB covers an area of approximately 100,000-km^2 (38,610 $mi.^2$). The hydrostratigraphic map consists of ten units (Faunt, 1997). Units were first delineated by grouping geological units by similar rock types, and second by similar hydrologic properties. A description of these hydrostratigraphic units is provided in USGS Water-Resource Investigation Report 95-4132 (Faunt, 1997).

The movement of surface and ground water through this hydrogeology framework has been studied using the USGS's numerical ground water model of the Yucca Mountain area (D'Agneses, et. al., 1997). D'Agneses (1997) used the hydrotratigraphy described above for his analysis.

3.0 Springs of Death Valley

The National Park Service (NPS) has identified 289 springs and seeps within the boundaries of DVNP. These springs and seeps were identified and cataloged by NSP Rangers starting in the late 1940's. Information collected on these springs and seeps is filed in four binders at the Environmental Services building in DVNP. A summary of information collected on these springs and seeps is provided in Appendix A. The locations of these springs are shown on Plate 7. The locations of these springs and seeps are accurate to the nearest $^1/_4$ section.

The springs in DVNP can be grouped into the following four types:

Type 1	Springs along Steeply Dipping Faults
Type 2	Mountain Springs
Type 3	Springs at Impermeable Structural Barriers
Type 4	Springs at the Edge of Alluvial Fans

3.1 Springs Along Steeply Dipping Faults

The springs with the greatest discharge are located along the steeply dipping Furnace Creek fault system between the Funeral and Black Mountain ranges (Plate 8). The major springs are named Nevares, Texas, and Travertine. These springs have an estimated total discharge of 158 liters per second (L/sec) (2,500 gallons per minute (gpm)), and are a water supply to the community of Furnace Creek. The springs discharge from the Paleozoic-age carbonates at the base of the Funeral Mountain range near the trace of the Furnace Creek fault. The spring orifices are marked by prominent white travertine mounds down-gradient. The source of water to these springs is of interest because they discharge from Paleozoic-age carbonate of the same age as the Lower Carbonate Aquifers at Yucca Mountain.

3.2 Mountain Springs

Mountain springs and seeps represent the greatest number of springs. Over 200 are listed in Appendix A. Most of these springs have small volumes of discharge. These springs are located at the higher altitudes in the Grapevine, Black Mountain, and Panamint Mountain ranges (Plate 7). A number of these springs are located at or near low-angle faults. The springs, for the most part, are located along intermittent creeks. Springs were observed to discharge from minor fractures in bedrock outcrops and from shallow soils. Springs can be located by the growth of willows at the spring orifice. Thus, the number of springs named "Willow" in DVNP. At a number of these springs the discharge is completely absorbed by associated vegetation. We observed spring discharge rates from negligible to 1.26 L/sec (20 gpm) with the average about 0.32 L/sec (5 gpm). Springs flows typically disappear less than 4.6 meters (15 feet) down-gradient of the spring.

3.3 Springs at Impermeable Structural Barriers

There are a limited number of springs emerging at impermeable structural barriers in and near the Salt Pan areas. The most noted of these springs is McLean that helps maintain flow of Salt Creek through the Salt Creek Hills (Plate 3). Two other examples of this spring type are Salt Creek spring and the small springs above the Park Service area at Nevares spring (Plate 7). The location of these springs near salt creek, and their close proximity to springs up-gradient suggest the source of water to these springs is the ponding of shallow ground water at relatively impermeable, structural barriers. Discharge from these springs is on the order of 0.63 L/sec (10 gpm), and typically has a high dissolved mineral content.

3.4 Springs at the Edge of Alluvial Fans

Springs at the edge of the alluvial fans along the salt pan at the base of the Panamint Mountain range represent the second most prolific springs in DVNP. The best known of these springs are Tule, Shorty

Wells, Eagle Borax, and Bennett Well (Plate 8). The water table below the coarse alluvial fan materials is estimated to have a slope of 7.6 to 15.2 meters per km (25 to 50 feet per mile). The water table is estimated to be several hundred feet below ground surface near the base of the mountain range, and at the land surface near the toe of the alluvial fan. Ground water discharges at the foot of alluvial fans at the Salt Pan. These springs commonly have associated willow and salt grass by open discharge channels. A distinct spring orifice is not evident at these springs. Total discharge from these springs is on the order of 95 L/sec (1,500 gpm) (Appendix B). Discharges from these springs typically have a high dissolved mineral content.

4.0 SPRING WATER SAMPLING PROGRAM

Less than 10 percent of known springs in DVNP have been sampled and analyzed. The sampling of springs for isotopic analysis by the USGS has been limited to the large discharge springs along the Furnace Creek Fault and along the alluvial fans on the east flank of the Panamint Mountain range. The USGS also sampled a select number of springs in the Black Mountain range for isotopic analysis. The results of chemical analysis of spring samples collected by the USGS in DVNP are provided in Appendix B.

The chemical composition of the higher altitude, Type 2, springs, and the Type 3 springs in DVNP is essentially unknown. Thus, our spring sampling program focused on the Type 2 and 3 springs; as these may provide insight into the source of ground water in DVNP. Our goal was to sample 25 additional springs in DVNP for chemical analysis. We initially identified 30 springs from the National Park Service's inventory of springs in DVNP, with the understanding that some of these springs may not be flowing. Criteria for selecting these springs included whether the spring had been sampled before, geographic location, type of spring source rock, reported discharge volumes, and access. Of the 30 selected springs, only 23 were flowing and/or accessible.

Water samples from 23 springs and 2 creeks in DVNP were collected, preserved, and shipped for analysis to the USGS's Denver laboratory, Huffman Laboratories, and Beta Analytical Laboratory by The Hydrodynamics Group's personnel (Table 2). A description of our sample collection and analysis procedures and the results of our study are provided below.

4.1 Sample Collection and Analysis Procedures

Water samples were collected, preserved, and shipped in accordance with U.S. Geological Survey Yucca Mountain Program ground water sampling protocols under the direction of Zell Petermen (Senior Geologist, U.S. Geological Survey, Yucca Mountain Project Branch). Each spring source was sampled once in this study. A summary of the analysis performed and information collected on each spring source is provided in Table 3.

4.2 Data Collected and Results of Analysis

The results of the analyses by the USGS, Huffman Laboratory, and Beta Analytical are provided in Tables 4 and 5. A summary of collected field data is provided in Table 6.

5.0 ANALYSIS OF GEOCHEMICAL SPRING DATA

Springs have proven useful in the characterization of flow systems because they are integrated samples of a ground-water flow system reflected in a single point of discharge. The geochemical composition and physical characteristics of spring waters can be representative of an entire ground water flow system, and therefore very conducive to regional ground water studies. The geochemical composition of springs can provides clues to the source, travel path, mixing of waters, and other processes within the ground water system.

Our evaluation of the geochemical composition of the springs of DVNP and the Yucca Mountain study area first established the chemical composition of the spring waters, which is provided in this section of the report. Secondly, we compared the regional geochemical composition, concentrations of isotopes, and the regional geological conditions to evaluate the source of the spring waters relative to the Lower Carbonate Aquifers below Yucca Mountain.

5.1 Chemical Composition of Springs (Piper Analysis)

Piper diagrams are an acceptable method to portray the chemical composition of spring waters. A trilinear "Piper" diagram (Piper, 1953) is a technique for displaying water chemistry data. The method graphically shows the relative concentrations of major cations (Ca^{+2}, Mg^{+2}, and K^{+}) and anions (CO_3^-, HCO_3^-, and

SO_4^-). Spring water of similar compositions will plot at or near the same position on a Piper diagram; this suggests a common source.

Piper diagram plots were prepared for springs sampled by mountain blocks (Plates 9, 10, 11, 12, 13, and 14). The index to the spring data points on Plate 9 is provided in Table 7 (Appendix B). Spring data points for chemical analysis provided by the USGS are designated by "spring name-USGS" (Appendix B).

The Piper diagrams of the DVNP springs indicate a very close match of chemical compositions for springs within a give mountain block (Plate 9). A description of the chemical composition of spring waters by mountain block is provided below.

The Piper diagram plot of the Grapevine springs indicates that all but two of the springs are located near the top of the recharge system (Plate 10). The very high HCO_3^- concentrations and very low concentrations of Na^+, Cl^-, SO_4^-, and Mg^{+2} indicate a very young ground water source. The springs sampled are at higher elevations near the winter snowfields, and are discharging from rhyolitic bedrock. Discharge rates ranged from a trace to over 20 gpm, and springs are located near intermittent creeks. The Stainger and Daylight springs differ from the other Grapevine springs in that they are localized intermittent seeps that pond water at the surface where it evaporates. Daylight spring was dry during our visit in May of 1998.

The Piper diagrams of the Funeral Mountain springs have very similar chemical compositions (Plate 11). These spring waters have high concentrations of Na^+, K^+, and Mg^{+2}, and intermediate concentrations of HCO_3^-, SO_4^- and Cl^-. This indicate water discharging from these springs has followed long travel paths. The source rock for these springs is carbonate. These springs are known for their association with travertine deposits at the spring orifices. The significance of these springs will be discussed in Section 6.0 and 7.0 of this report.

The Black Mountain springs can be described as a mixed bag of sources, based on the wide range of chemical compositions on the Piper diagrams (Plate 12). The Ibex, Lemonade and Salisburg springs have similar chemical compositions, but are not geographically near each other. The high concentration of NaCl and moderate concentration of HCO_3^- in these three spring waters indicates a small localized ground water flow path. Water discharging from these three springs was observed to pond, and eventually evaporates. The Willow spring is unique in that it plots near the center of the piper diagram (Plate 12). Willow spring is the discharge point for Gold Valley. Gold Valley is a higher altitude colluvial filled valley. The valley is composed of a wide range of metamorphic and igneous rocks. The chemical composition and location of Willow spring in Gold Valley suggest the source of water is discharge from the colluvial materials and basement rock.

The Piper diagram for the Panamint Mountain range springs reflect a range of composition that are indicative of their source rocks (Plate 13). The chemical composition of these springs shows very high concentrations of Ca^{+2}, and very low concentrations of NaCl and Mg^{+2}. The wide ranges of HCO_3^- and SO_4^- are indicators of the maturity of the water. A mature water will have a higher concentration of SO_4^- and a lower concentration of HCO_3^-. The opposite is true for intermediate-mature water. The more mature waters are from springs discharging from carbonate rocks, like Dripping spring. The C^{14} determined age of Dripping spring is about 7,000 years. The relatively higher concentrations of $CaSO_4$ in this water indicate a source of gypsum and/or other hydrothermally deposited minerals. There are a number of higher altitude small mining operations, near the Lime Kiln spring that are associated with hydrothermal deposits.

The Piper diagrams for the Death Valley Salt Pan springs are totally dominated by evaporation processes, with concentrations of NaCl exceeding that of sea water in some springs (Plate 14). These waters have essentially no concentrations of Ca^{+2}, Mg^{+2}, and HCO_3^-. The concentrations of SO_4^- are low to moderate suggesting these waters had sulfates in them prior to evaporation. The composition of the Eagle Borax Spring is similar to Panamint Mountain springs, which suggest this is a fault controlled spring source.

5.2 Stable Isotopes of Deuterium and Oxygen-18

The stable isotopes of deuterium and oxygen-18 are useful in the interpretation of a spring source; these isotopes provide a signature of the recharge source, a means to evaluate the evaporation history of the water, and a means to evaluate certain rock-water reactions. The analysis of these isotopes can allow a constrained interpretation of ground water flow path. The isotope data is especially useful (when combined with other parameters), such as general water chemistry, type of spring source rock, and discharge rates.

Deuterium and oxygen-18 values are plotted on Plate 15. The Modern Water Line (MWL) is shown as a guide to average composition trends (Craig, 1961). Frequently, waters of the Great Basin plot slightly to the right of the MWL. This is because of evaporation during liquid precipitation in the generally dry atmosphere.

A considerable portion of the precipitation in the higher mountains is snow. Water samples from this water source plot on or just above the MWL, which is evident in the deuterium and oxygen-18 values for the Grapevine and some of the Panamint springs. For example, Johnnie Shoshone spring, a higher altitude spring in the Panamint Mountain range, plots to the left of the MWL. The spring has a relatively small catchment area, with recharge from a large number of winter snowstorm events. The higher altitude Panamint Mountain range's Hummingbird and Thorndike springs plot nearly on the MWL. The Wildrose spring differs from this pattern by plotting to the right of the MWL. Wildrose spring is located in the same drainage basin as these three springs, but at a lower elevation (approximately 1,250 m (4,101 feet) elevation). Discharge from Wildrose spring appears to be from a much larger drainage area. The Lime Kiln, and Upper Emigrant springs also represent discharge from relatively large drainage basins in the Panamint Mountain ranges, and plot just right of the MWL.

A number of moderate elevation springs 1,000 to 3,000 m (3,281 to 9,843 feet) in elevation show a strong shift to the right of the MWL; this reflects the influence of evaporation. Ibex and Salsberry springs in the Black Mountain range have small spring catchments that experience evaporation. The Navel Springs in the

Funeral Mountain range also shows an evaporation effect, and influence from localized recharge. The Navel springs have a significantly heavier isotopic signature than the Texas, Travertine, and Nevares springs in the Funeral Mountain range. The Texas, Travertine, and Navares springs plot very close to the MWL. It is believed Texas, Travertine, and Nevares springs represent an older interbasin carbonate rock flow system. These springs also reflect more pluvial Pleistocene climate age waters, thus the lower isotopic values.

The Salt Pan springs show the greatest shift to the right from the MWL. All of the Salt Pan springs (McLean, Buried Wagon, Saratoga, Owls Hole, and Salt Creek) have gross water chemistries indicating dissolution of evaporates, primarily halite (NaCl) and some sodium sulfate minerals.

5.3 Uranium $^{234}U/^{238}U$ Isotopes

The uranium content in groundwater and ratio between the uranium isotopes of $^{234}U/^{238}U$ may provide insight into the source of the water (Ludwig et., al., 1993). Paces, et al. (1998) states:

> *Uranium-234 is an intermediate decay product of ^{238}U, which, if undisturbed, reaches a state of secular equilibrium, activity (decays per unit time) of the daughter is equal to that of the parent such that the $^{234}U/^{238}U$ activity ratio = 1.0 in solid materials older than several million years. In contrast, oxygenated ground waters in southern Nevada have $^{234}U/^{238}U$ ratios that are nearly always greater than those in surface runoff ($^{234}U/^{238}U$ activity ratios commonly between 1.5 and 2.0; J.B. Paces et al., USGS, written comm., 1996) or soil-zone materials (initial $^{234}U/^{238}U$ ratios of 1.3 to 2.0). Therefore, elevated $^{234}U/^{238}U$ signatures are obtained by incorporating ^{234}U preferentially to ^{238}U along flow paths due to processes related to the effects of radioactive decay in the adjacent wall rock. The dominant mechanisms are preferentially leaching of ^{234}U from radiation-damaged lattice sites (Szilard-Chalmers effect), radiation-induced oxidation of ^{234}U leading to a more soluble uranyl ion, and alpha-recoil of ^{234}Th off of crystal surfaces. The amount of ^{234}U excess relative to ^{238}U is limited by rates of ^{234}U decay, water rock ratios, flow-path length, and the amount of bulk-rock dissolution from the aquifer. These factors typically result in*

$^{234}U/^{238}U$ activity ratios between about 2 and 4 in most southern Nevada ground water.

DVNP springs are relatively rich in uranium. Two potential sources of uranium are hydrothermal mineralization, (Panamint mountain range springs) and uranium concentrated by evaporation (Salt Pan springs).

The springs with the highest concentration of uranium are the salt pans springs of Buried Wagon, McLean, Salt Creek, Owls Hole, and Saratoga, which range between 16.22 and 25.22 parts per billion (ppb) uranium (Table 5). These springs have $^{234}U/^{238}U$ activity ratios that range between 1.25 and 1.73. The concentration of uranium in the Panamint springs of Johnnie Shoshone, Upper Emigrant, and Anvil range between 8.502 to 21.244 ppb. These springs have $^{234}U/^{238}U$ activity ratios that range between 1.25 and 2.83.

Paces, et., al. (1998) plotted uranium concentrations versus $^{234}U/^{238}U$ activity ratios for well and spring waters in the DVDB (Plate 16). Plate 16 also includes a plot of uranium concentrations versus $^{234}U/^{238}U$ activity ratios for Death Valley spring. Paces, et., al. (1998) states: *that ground water associated with carbonate, alluvial, and Precambrian-rock aquifers from Oasis Valley, Amargosa Valley, Spring Mountains and easternmost NTS (Nevada Test Site) have $^{234}U/^{238}U$ activity ratios of about 1.5 to 4.* Paces, et., al. (1998) further indicates waters from volcanic-rock aquifers beneath Yucca Mountain and western Yucca Flat commonly have values greater than 4, with anomalously high values of over 7 in shallow (saturated zone) wells. The $^{234}U/^{238}U$ activity ratio for Lower Carbonate Aquifer waters from UE-25p1 was 2.32. Paces, et., al. (1998) further indicates waters with the most elevated $^{234}U/^{238}U$ activity ratios (about 6) appear to be restricted to uranium concentrations less than about 3 ppb. The uranium concentrations and $^{234}U/^{238}U$ activity ratios for the Death Valley springs are consistent with Paces' observations for other well and spring waters in the DVDB.

5.4 Strontium Isotopic Ratios Analysis

The strontium isotope ^{87}Sr is a daughter of rubidium-87. Strontium chemically behaves similar to calcium and magnesium, but is not as abundant. Concentrations of ^{87}Sr and ^{86}Sr will vary for different rock types. For example, ^{87}Sr is found in greatest abundance in granitic and syenitic igneous rocks.

Evaporates and marine sedimentary rocks contain abundant strontium, but normally have a lower concentration of ^{87}Sr. Igneous and volcanic rock have intermediate concentrations of ^{87}Sr. Because of this variation in concentrations of strontium isotopes by rock type, isotopic ratios of $^{87}Sr/^{86}Sr$ in ground water, expressed in per milliliters of ^{86}Sr in seawater, can provide a means of evaluating the source of the water.

The concentration of strontium and relative abundance of ^{87}Sr in the Death Valley spring waters are consistent with the general interpretations of water source areas previously discussed. For example, higher concentrations of strontium isotopes in Panamint Mountain springs are consistent for granite pluton rock type. The Tertiary pyroclastic volcanic rocks of the Grapevine Mountain springs have relatively low concentration of strontium isotopes. The relative high concentration of strontium isotope, and intermediate concentration of ^{87}Sr in the Death Valley salt pan spring water are indicative of evaporate deposits. The Willow spring in the Black Mountain range has a low concentration of strontium, and intermediate concentrations of ^{87}Sr. The low concentration of strontium is typical for a metamorphic rock type, but the intermediate concentration of ^{87}Sr suggests an eolian source from the alluvial basin sediments. The concentration of ^{87}Sr from 11.1 to 13.9 per milliliter in the Furnace Creek area springs (Travertine, Texas, and Nevares) are in the same ranges as the Big Bore and Last Chance springs, located just south of the Ash Meadows springs.

6.0 INTERPRETATION OF REGIONAL FLOW

In discussing the regional flow of the area there are several areas worthy of special discussion—the Furnace Creek area, Yucca Mountain and the Nevada Test Site (NTS), Ash Meadows, the Amargosa Valley, and finally the mountains in the vicinity of Death Valley.

6.1 Regional Hydrogeology

The Ash Meadows springs represent a window in the middle of the larger lower carbonate flow system. Up-gradient from the Ash Meadow area the carbonate aquifer is confined. The limited available hydraulic head information suggests that the potential for flow may be upward from the lower carbonate aquifer into the overlying alluvial fill of the Amargosa Desert basin. There may be a small amount of upward leakage. The exploratory holes being drilled by Nye County in early 1999 should provide more data on the hydraulic head in the area of the Amargosa Desert to the south of Yucca Mountain.

At the west margin of the area the lower carbonate aquifer is exposed in the Funeral Mountains; however, there is no hydraulic head information in this area. Within Funeral Mountains there are numerous faults. The fine-grained basin fill of the Amagora Desert terminates against the Funeral Mountains; this truncates the fine-grained basin-fill deposits and thus eliminates the obvious confining layer for the lower carbonate aquifer.

The Furnace Creek Fault Zone trends NW on the Death Valley side of the Funeral Mountains. It forms a barrier for further westerly flow in the lower carbonate aquifer. The fault provides localized conduits for upward flow through the Pleistocene and Pliocene sediments; this flow forms the Furnace Creek springs.

In the zone where the majority of springs occur, a splay of the major fault zone—the Greenwater Valley Fault, meets the Furnace Creek Fault Zone. The two faults form a graben 0.64 km (0.4 mile) wide. Within the graben are highly deformed and faulted Pliocene fine-grained sediments that are overlain by less deformed Pleistocene alluvial fan deposits. The alluvial fan deposits are also faulted. It is along these faults, within the fine-grained sediments, where the larger springs occur.

The Furnace Creek Fault Zone shows evidence for repeated lateral and vertical movements. It is a regional, deep-seated, transverse fault zone that has both segments with major vertical movement, and other segments with lateral movements. It forms the east flank of Death Valley along the Funeral Mountains; further to the north it bounds the eastside of the White Mountains.

One primary splay of the Furnace Creek Fault Zone extends southward to the west of the Resting Spring Range, down the Amargosa Valley to the Tecopa area. This Furnace Creek Fault is also the regional structural feature that terminates the lower carbonate aquifer in the Tecopa area. It controls the discharge from the carbonate aquifer both in Death Valley and to the south in the Shoshone and Tecopa areas.

There is evidence of a long history of flow in the lower carbonate aquifer. Paleo-Spring features occur in the Tecopa area, along Furnace Creek, and eastward in the Ash Meadows area. In the Death Valley area the paleo-springs occur where the Furnace Creek Fault Zone and associated faults establish the westerly limit of the lower carbonate aquifer. Along Furnace Creek travertine filled veins and travertine spring deposits occur within the Pleistocene alluvial fan deposits. These paleo-spring features appear to represent a period of significantly greater flow within the carbonate system. Winograd and Doty (1980) have recognized similar paleo-springs, of uncertain age, high above Furnace Creek at altitudes much greater than the current base level.

To the south in Tecopa Valley, along the bajada flanking the Resting Spring Range, travertine spring deposits occur associated with pluvial lake, beach deposits. These springs were also controlled by north-south faults associated with the Furnace Creek Fault Zone. Morrison (1999) dated the beach deposits in the Tecopa area at approximately 200,000 years before present. The deposits formed from thermal springs during the highest stand of Lake Tecopa. Later the lake basin was breached, and the Amargosa River drained to Death Valley.

These paleo-spring features are significant in that they suggest:

1) periods of higher hydraulic head in the past—perhaps as old as the late Pleistocene, ~200,000 years ago;
2) such paleo-spring features are recognized only in areas where major faults form deep- seated barriers to interbasin regional flow; the faults cause discharge from the carbonate rock system.

Most of the paleohydrologic features in this area of the carbonate rock province are not as well dated; however, the Tecopa area features are dated at 200,000 years in age. These old features suggest that tectonic movements in the area have not changed the flow system markedly from that which existed during the Pleistocene pluvial period. The spring areas of the past have been maintained in the same areas. The thermal character of the paleo-spring features suggests deep circulation within a confined system.

6.2 Furnace Creek Springs

The Furnace Creek spring area has large and small springs, and seeps; they combine to produce a discharge that is greater than 6,615 m^3 per year (5000 acre-feet per year) (Hunt et. al., 1966). These springs are interpreted as discharge from the regional carbonate aquifer. The discharge is too large to come from a drainage basin in the adjacent Funeral Mountains—a basin approximately 1,036 km^2 (400 square miles).

The source of these springs is an important consideration for the disposal of nuclear wastes at Yucca Mountain. If the major flow to the Furnace Creek spring is from Ash Meadows and to the east, then the risk of radionuclide transport from Yucca Mountain is reduced. If, on the other hand, the major flow path is from Yucca Mountain and NTS, then the risk is greater. It is this question that is the focus of our work.

6.3 Yucca Mountain Recharge

The UE 25-P1 drill-hole at Yucca Mountain was a 1,798 meter (5,900 foot) deep exploratory hole that penetrated 487 meters (1,600 feet) of Paleozoic carbonate rocks underlying the volcanic tuffs. It is the only drill hole at Yucca Mountain to have penetrated the lower carbonate aquifer. The borehole encountered carbonate rock beneath a fault zone believed to have significant displacement.

The hydraulic head measured in the carbonate rock is approximately 18 meters (60 feet) higher than that measured in the overlying volcanic tuff sequence. This indicates that any flow, or leakage, is upward from the carbonate aquifer into the Tertiary volcanic rocks in that area.

The major ion chemistry of the carbonate aquifer water is that of a regional aquifer. The major ion chemistry is similar to that of Texas and Travertine springs in Death Valley, and different than that of the Ash Meadows springs. The Ash Meadows springs are more dilute in the major ions; this may suggest that there is an important different source of recharge for Ash Meadows. Most researchers now agree that much of the water in the springs of Ash meadows is from the Spring Mountains.

The deuterium in the UE 25-P1 carbonate water is -107 units, too light for either Ash Meadows or the Furnace Creek area waters. This indicates that carbonate water from Yucca Mountain must be mixed with water containing heavier deuterium to reach the deuterium values observed in Furnace Creek spring waters.

In conclusion, it is likely that UE 25-P1 carbonate rock water is old, and that it represents a slower zone of flow within the carbonate rock flow system.

6.4 Recharge From Amargosa Desert Basin Fill

The data for wells in the Amargosa Desert is limited. There are 26 wells with gross water chemistries; 20 of these have stable isotope analyses. The average deuterium content is -102 units, and average oxygen-18 content is -13 units. The deuterium ranged from -98 to -105 units, and oxygen-18 from -12.6 to -13.8 units. Both the deuterium and oxygen-18 values are slightly heavier than the Furnace Creek spring waters, but individual analyses overlap the Furnace Creek data.

Claassen (1985) suggested that the Amargosa Desert basin-fill waters came from several sources: 1) carbonate aquifer water, 2) water recharged from surface flows in the Amargosa River and Forty Mile Wash, and 3) water from the volcanic aquifers to the north in the area of NTS. Claassen (1985) recognized the possibility of upward leakage of ground water along the same fault that localizes the Ash Meadow springs. Water from wells in the Amargosa Desert has deuterium and oxygen-18 contents that are similar to the Ash Meadow springs.

6.5 Ash Meadows Springs

The discharge of the Ash Meadows springs is estimated to be approximately 20.96 x 10^6 m^3 per year (17,000 acre-feet per year). Hunt et al. (1966) hypothesized that ground water is recharged in the Spring Mountains. It then flows westward to the Ash Meadows area then on to Death Valley. The Ash Meadows springs are approximately halfway along the postulated flow path.

Winograd and Thordarson (1975) mapped the regional head in the lower carbonate aquifer. Their map suggests ground-water flow form the northeast side of the Spring Mountains, around the northwest extension of the range, to the Ash Meadows springs. This interpretation differs from that of the Hunt et al. (1966); Hunt et al. suggested a flow path directly west from Pahrump Valley to Ash Meadows.

The major flow path for ground water now appears to be from the north side of the Spring Mountains. This northern flow supplies the bulk of the water to the Ash meadow springs. With this interpretation, it is the combination of ground water from NTS mixed with a larger percent of Spring Mountain derived ground water that supplies the Ash Meadow springs.

One can compare the isotopic data for the Ash Meadows spring water with that from the Furnace Creek springs. One interpretation is that the Furnace Creek regional springs are the result of flow that bypasses the Ash Meadow springs; the Death Valley springs in this interpretation are the down-gradient extension of the Ash Meadows regional flow system. The deuterium/oxygen-18 isotopic composition of the water suggests that there is no significant source of recharge between Ash Meadows and the Furnace Creek area. There is about 48 km (30 miles) of travel distance between Ash Meadows and Death Valley.

Local and small-local "carbonate" flow systems occur in both the Spring Mountain and Pahrump Valley. These local and small-local flow systems have water with almost no Na+K of $Cl+SO_4$. Water from the Ash Meadows Spring has a major ion content that is typical for a regional carbonate system. However, the water from Ash Meadows has only approximately 50% of the Na+K and $Cl+SO_4$ that is present in the Furnace Creek springs.

The major ions of Na+K, $Cl+SO_4$ increase significantly between Ash Meadows and Furnace Creek, while the stable isotopes are unaffected. One explanation for the increase in major ions is dissolution from the carbonate rock of minerals, principally gypsum, that increases the Na+K, and $Cl+SO_4$ content of the water; Mifflin favors this explanation. Winograd, on the other hand, argues there is little, or no gypsum in the carbonate rocks in this area. He suggests there must be a contribution of other water high in $Cl+SO_4$ along the flow path to the Furnace Creek springs.

The limited hydraulic head data in the area suggests regional flow is from Pahute Mesa to Yucca Flat then southwest to Oasis Valley. To the south the flow is toward the Amargosa Desert, and continuing to the Ash Meadows springs. There is a significant range in the deuterium values from these areas; the variation is 8 to 10 deuterium units. The variation suggests different ages for the waters.

An explanation for the variation in deuterium isotopes is that there is a significant component of old pluvial climate derived recharge in some, if not most, the deeper flow systems both in the larger basin-fill aquifers as well as parts of the regional carbonate flow system. Flow within parts of these systems may be sufficiently slow to still contain water that is more than 12,000 years old.

A mix of deuterium data from young and old water may be misleading in identifying recharge areas for the regional carbonate aquifer. The isotope analyses for the Ash Meadows spring waters may pose such difficulties. The contribution from the Spring Mountain and the Sheep Range contribution may be significantly underestimated. The data suggests that the combined recharge in northeastern portion of Las Vegas Valley had an average deuterium content of -103 units—representing recharge that occurred during an earlier pluvial climate. The data from the local-small springs in the surrounding mountain ranges indicates that the current recharge has a deuterium content no lighter than -96 units. There may be a difference in the deuterium content of -7 units between recharge in an earlier pluvial climate recharge and recharge today.

Thomas et al. (1996) suggested that 40% of Pahranagat Valley water, with an average deuterium content of –109 units, mixes with 60% of Spring Mountain water, with an average deuterium content of -99 units, to yield the observed deuterium content of the Ash Meadow spring water, -103 units. Mifflin suggested that if the average deuterium content of the Spring Mountain recharge is -97 units then a 50/50 mix results. This demonstrates how sensitive the calculations of recharge area are to small changes in isotopic composition. There is no independent evidence for recharge coming from Pahranagat Valley.

The stable isotope data is insufficient to be used exclusively to identify the areas of recharge regional flow systems within the carbonate rocks. In some areas where the water may be quite old the interpretation is made more difficult by the potential shift in deuterium/oxygen-18 composition between the present climate and an older pluvial climate. Mifflin suggests that the regional deuterium data indicate a variation between the current recharge and older pluvial climate recharge of 6 to 7 deuterium units.

6.6 Springs in the Vicinity of Death Valley

We collected samples of water from 23 springs in the vicinity of Death Valley, as previously discussed. Most of these were in the mountain ranges that surround the valley. When we plotted the chemistry of the water on Piper diagrams the water from the various mountain ranges grouped nicely; the major ion water chemistry has a distinct signal for each mountain range. This reflects the fact that the major ion water chemistry takes on a distinct character from the local geology.

6.7 Local Recharge in the Funeral Mountains

It is probable that some recharge to the lower carbonate aquifer occurs through the carbonate rocks of the Funeral Mountains. This is even more probable because of the carbonate rocks are highly fractured and faulted in the Funeral Mountains. There are no high-altitude springs in the Funeral Mountains that can be used to directly characterize the stable isotopic signatures of local recharge.

At first glance, Navel spring appears that it may represent local recharge. However, Navel spring waters have stable isotope signatures that indicate low altitude recharge and some evaporation; these waters are too heavy to be representative of local recharge in the Funeral Mountains.

The major spring waters—Texas, Travertine, Nevares—are clearly too light in stable isotopes to be derived entirely from local recharge.

The total amount of local recharge in the Funeral Mountains is estimated to be approximately four times larger than the recharge in Gold Valley in the Black Mountains. Gold Valley is similar in elevation; water from Gold Valley is expected to have a stable isotopic signature similar to the recharge area in the Funeral Mountains. Willow spring in Gold Valley has an average discharge between 2.5 to 3.15 L/sec. (40 and 50 gpm). This is about 6% of the discharge of the Furnace Creek springs. Willow Spring water has a deuterium content of –92 units, and an oxygen-18 content of -11.4 units.

Assuming that the local recharge in the Funeral Mountains is similar in isotopic composition to Willow spring water, it requires only 6% Funeral Mountain local recharge water mixed with Ash Meadow spring water to yield water that is the same isotopic composition as water in the Furnace Creek springs.

7.0 HYDROGEOCHEMICAL INTERPRETATIONS

The large springs at the base of the Funeral Mountains in Death Valley are an enigma. The discharge is too large—6.125×10^6 m^3 (5000 acre-feet/year)—to be recharge from the associated, nearby drainage basins in the Funeral Mountains. The suggestion is that these springs are supported by inter-basin ground-water flow in the lower carbonate aquifer.

A number of investigators have hypothesized the source of these springs. Most of these ideas have been based upon the similarity of the spring water chemistry to other ground water in the region. The various investigators have used both the major ion and the isotope chemistry of the water. The question arises, after collecting and analyzing waters from another set of springs during this investigation—most of them in the vicinity of Death Valley, whether we can further constrain the source of the water for the springs of Furnace Creek.

There are several interpretations for the source of these springs. Hunt et al. (1966) suggested the source was in the Springs Mountains (south of Las Vegas) about 80 km (50 miles) to the east. In Hunt et al. (1960) the interpretation is that ground water would flow through the lower carbonate aquifer along a path through Pahrump Valley to Ash Meadows and then to Death Valley.

Winograd and Thordarson (1975) observed that ground water from the springs in the Ash Meadows Area, and in the alluvial fill along the Amargosa River is similar in gross chemistry to the water of the Furnace Creek springs. (Winograd and Thordarson (1975) published a U.S. Geological Survey Professional Paper on the geochemistry of ground water in the area of the Nevada Test Site (NTS). This publication was a long time in process. Winograd and Thordarson worked at NTS for almost a decade in the 1960s; their ideas were widely discussed long before the their Professional Paper was published.) They suggested that at least some of the recharge for both the springs at Ash Meadows and in the Furnace Creek area in Death Valley came from the north in the vicinity of NTS.

Mifflin (1968) studied the hydrochemical facies of carbonate rock flow systems in Nevada. He compared the water chemistries of all large discharge springs (greater than 9.5 L/sec. (150 gallons per minute)) within the region in which the "bedrock" is dominated by carbonate rock—his so-called "carbonate rock province". Mifflin found that as the length of a ground-water flow path increased in the carbonate rock, the "conservative" major ions of Na+K and $Cl+SO_4$ continued to increase in concentration. On the other hand, the Ca+Mg and HCO_3+CO_3 content of the water generally remained at, or close to, saturation with respect to the carbonate rocks of the aquifer. Mifflin used other supporting data, such as presence or absence of atomic bomb-derived tritium, geographic and terrain information, water budgets, and a few carbon-14 analyses that indicate apparent age of the water, to support his hypothesis. He argued that the weight of the evidence supported the idea that the length of ground-water flow path determined the widely varying concentrations of the major ion chemistry of the water. The length of the flow path is a surrogate measure for the residence time of water in the aquifer.

Mifflin (1968) went on to suggest that the flow systems as interpreted from the spring water chemistries could be subdivided into three flow systems: 1) small-local, 2) local, and 3) regional. The division between the water chemistry of "local" and "regional" springs was established by comparing the chemistry of known regional (interbasin) springs (established by evidence other than chemistry) with the chemistry of known local springs. The chemistry of local and regional springs differs by approximately one equivalent per million (epm) for Na+K and Cl+SO_4.

Claassen (1985), based upon a study of hydrochemistry, suggested Amargosa Basin fill waters may be derived, at least in small part, from the volcanic terrain in the Yucca Mountain area.

Johnson (1980) studied the temporal relationships of water chemistry, discharge, and tritium content of a group of "small-local" and "local" springs along the East Side of the Ruby Mountains. Johnson's (1980) investigation reinforces Mifflin's idea of shallow flow systems for the "small-local" springs and deeper, larger flow systems for the "local" springs.

The major ion ground-water chemistry in both carbonate rock and basin-fill, regional flow systems may be quite similar. The stable isotopes of deuterium and oxygen-18 have been used to identify areas of recharge. Winograd and Friedman (1972) were the first to use the stable isotope deuterium as a tracer; they showed that deuterium varied in concentration in recharge areas within Mifflin's carbonate rock province.

Winograd and Friedman demonstrated that stable isotopes in water were a potentially powerful technique that could be used to interpret source areas for the large regional flow systems. Kirk and Campana (1980), Claassen, (1985,1986), Lyles and Hess (1988), Novak (1988), Hershey and Mizell (1995), Thomas et al. (1996), and Pohlmann et al. (1998) revisited the general spring hydrogeochemistry within Mifflin's carbonate rock province. They considered the stable isotopes of deuterium and oxygen-18, as well as other isotopes, and trace constituents in the spring waters.

In this investigation we sampled and analyzed the water chemistry of an additional set of springs in the immediate vicinity of Death Valley. One of the objectives was to help further characterize the ground water in the Death Valley mountain blocks, and to determine the source of these waters. Specially, we are interested in how much of the water in the Furnace Creek springs (Lower Carbonate Aquifer springs) comes from a local source, and how much comes from the Amargosa Valley and Yucca Mountain areas.. We hoped to constrain the local recharge by looking again at the hydrochemistry of the water.

In using the geochemistry of the spring water for interpreting sources and flow paths there are three, more or less, independent data sets. The first is the major ion composition of the water. The second is the stable isotope composition of the water—most of this data is for deuterium/oxygen-18. The third is the age dating of the water using tritium, or carbon-14 age of the water.

7.1 Major Ion Chemistry

Winograd and Thordarson (1975) used the major ion chemistry of the ground water in the lower carbonate aquifer to suggest the source of recharge. For the carbonate springs in Death Valley they suggested three potential recharge areas: 1) the Nevada Test Site area, 2) the Amargosa Desert, and 3) the area to the east in the Spring Mountains that supplies much of the Ash Meadow springs.

Winograd and Thordarson (1975) based their interpretation on the major ion chemistry of waters from these areas. The major ion constituent chemistry of water from well 16/48-17a1 in basin-fill alluvium, on the west side of the Amargosa Desert, is very similar to water from Navares, Texas, and Travertine springs in the Furnace Creek. The major ion chemistry of water from the Ash Meadows regional springs, that also discharge from the lower carbonate aquifer, are similar; however the Ash Meadow water has less Na+K and $Cl+SO_4$. The chemistry of the Pahrump Valley—Spring Mountain waters are significantly different; they have almost no Na+K and $Cl+SO_4$.

7.2 Isotopes—Deuterium/Oxygen-18

Craig (1961) defined a relationship between deuterium and oxygen-18 that he defined as the ***meteoric water line (MWL).*** Craig suggested that precipitation from all over the world should fall along the MWL. It is this hypothesis of Craig's that forms the basis for much of the use of deuterium and oxygen-18 as tracers in water. Plate 15, adapted from Thomas et al. (1996), shows the relationship between deuterium and oxygen-18 for ground water from our area of interest.

The data from southern Nevada and southwestern California are shifted slightly to the right from Craig's (1961) global MWL. Water that has undergone evaporation becomes heavier in oxygen-18 with respect to deuterium because of fractionation caused by evaporation. This suggests that water that plots to the right of the MWL has undergone evaporation; the further the data plots further to the right of the MWL, the more evaporation is indicated.

Precipitation in the arid region that occurs in liquid form evaporates slightly during fall through the atmosphere. This explains the shift to the right in the majority of the data from this area of southern

Nevada and southwestern California. Precipitation that occurs as snow or ice does not evaporate and fractionate; we expect these waters to plot closer to the MWL. Water that is strongly shifted to the right of the MWL indicates that these waters have undergone significant evaporation.

Both deuterium and oxygen-18 in precipitation are influenced by a number of factors related to moisture sources, to storm path histories, and air temperature. Deuterium and oxygen-18 concentrations in ground water in recharge areas, as represented by small-local springs and shallow wells in mountainous areas, are an integrated sample of summer and winter precipitation. Geography, especially altitude of the recharge area, is important in determining the deuterium and oxygen-18 content of recharging ground water. A further complication that may enter into interpretations is the age of the ground water.

A large, and independently derived body of evidence indicates cooler to significantly colder pluvial climates existed in the region in the not too distant past. The cooler climate should have produced precipitation that is lighter in deuterium and oxygen-18 than water recharged during the current, and warmer, interglacial climate of the region. There are two conditions for the recharge in the large regional flow systems:

1. all the recharge in these large systems is younger than the last major pluvial climate in the region—approximately 12,000 years ago, or
2. some of the water is older than 12,000 years and is pluvial.

If some of the water is older than 12,000 years, the interpretation of recharge areas based upon the deuterium/oxygen-18 isotopic composition is more complex.

Thomas et al. (1996) concluded that deuterium in water, from a set of samples from recharge areas in the Spring Mountains and the Sheep Range, did not show a trend towards lighter values with greater apparent age. He inferred the age of the water from the carbon-14 content of the water (the percent modern carbon); his ages are only relative. All the water analyzed by Thomas et al. appears to be associated with the modern MWL.

Mifflin reviewed for this study the currently available deuterium data within the region that we and other researchers collected—displayed in Plate 15, (Thomas et al., 1996). Mifflin suggested, based upon his review of the data for the region, that some of the water in the deeper parts of the flow system appears to be lighter in deuterium. Mifflin commented that the water used by Thomas et al. (1996) in their analysis is from the mountain ranges in areas where one would expect the water to be younger than 12,000 years.

Mifflin went on to suggest that deuterium is generally lighter (higher values) in the known regional carbonate springs than in the potential recharge areas as outlined by Thomas et al. (1996). Values from the basins many be more negative than -100 units (more negative values are lighter). Mifflin argues that the general relationship of light deuterium values in the basins with heavier values in the mountains indicates that we are dealing with of two different ages of water—an old, lighter water, and a more recent heavier water. Undoubtedly, any shift in the MWL occurs gradually as climate changes, and there is a continuum from light to heavier—it is not purely bimodal.

These interpretations assume that the precision of the deuterium determinations is within 1 or 2 tritium units. Tritium is hard to analyze; such precision is hard to achieve, especially when more than one laboratory does the analyses. Therefore, spring sampled for this study were not analyzed for tritium.

Regardless of the problems that attend interpretation of stable isotopic data, once the water is in the confined portions of regional carbonate aquifer flow systems the isotopic composition of the water remains unchanged, especially deuterium. The isotopic composition remains constant over considerable distances and time. The composition changes as waters from differing sources mix.

7.3 Carbon-14

The carbon-14 ages are problematic in the Lower Carbonate Aquifer because of the potential for carbon exchange with the rock. A number of investigators have attempted to correct the carbon-14 ages using various techniques. None of these attempts is very convincing. Older carbon-14 dates are only suggestive; the carbon-14 dates cannot be used quantitatively in the Lower Carbonate Aquifer. Therefore, the results of our carbon-14 analyses was not used for comparative analysis with Lower Carbonate Aquifer carbon-14 data from other sources.

8.0 CONCLUSIONS

The water sampled and analyzed from small-local springs in mountain ranges in the vicinity of Death Valley have a major ion signature that groups the waters nicely by mountain range.

By comparing the deuterium content of the large regional springs in the Furnace Creek area with the deuterium content of the small-local springs in the Death Valley area we can constrain the amount of local recharge to the carbonate aquifer in the Funeral Mountains. The amount of local recharge is less than 10%

of the regional spring discharge in the Furnace Creek area. This is further evidence that the major springs in the Furnace Creek area discharge from the regional carbonate aquifer.

The question of the ultimate source of recharge for the Death Valley carbonate springs remains unanswered. The three possibilities outlined originally by Winograd and Thordarson (1975) remain possibilities. The water can come from recharge in 1) the area of NTS and Yucca Mountain; or 2) the Amargosa Basin fill deposits, or 3) the area to the east that includes the Ash Meadow springs, or some combination of all three. We now know that the local recharge is quite small.

The deuterium/oxygen-18 data suggest that some water in the Lower Carbonate Aquifer may have come from recharge that is older than 12,000 years, from a time when the climate was cooler and wetter. This cooler and wetter climate had isotopes of deuterium and oxygen-18 that were lighter; they represent a shifted MWL during the cooler, wetter climate.

9.0 RECOMMENDATIONS

The results of this study suggest the need to further characterize the springs and hydrogeology of the Death Valley area, and to better understand the hydraulic connection between the Funeral Mountain springs and the Lower Carbonate Aquifer beneath Yucca Mountain and the Amargosa Valley. It is recommended that additional springs be sampled and analyzed for major anion and cations, and stable isotope concentrations. We further recommend the drilling of two exploratory wells east of the Funeral Mountains to further evaluate the possible hydraulic connection between the springs in Furnace Creek area and the Lower Carbonate Aquifer

The Death Valley springs in the Furnace Creek area, upper Funeral Mountain range, Grapevine Springs area near Scotty's Castle, and the Cottonwood Mountains have not been fully characterized in terms of discharge rates and water chemistry. Further characterization will help to determine the source of spring waters in the northern portions of the Death Valley area, and from the carbonate springs in the Furnace Creek area. It will also improve our understanding of the hydrogeology of the Death Valley area in terms of recharge and water balance. We recommended selected springs be characterized and sampled according to the sampling protocols developed for this study.

Our understanding of the hydraulic connection between the Funeral Mountain springs and the Lower Carbonate Aquifer would be improved with 1) the drilling of two exploratory monitoring wells, and 2) chemical analysis of water from the Ash Meadows springs and wells in the Amargosa Valley. We recommend the drilling and construction of two approximately 460 meters (1,500 feet) deep monitoring wells on the east side of the Funeral Mountain range. One of the wells should be along an extension of the Furnace Creek fault in the Amargosa Valley. The wells should be designed to allow geological logging of drill cutting, water sampling from selected aquifers for chemical analysis, and water level measures in the Lower Carbonate Aquifer. Water samples should be collected from these two wells and from selected springs and wells in the Amargosa Valley, according to the protocols developed for this study.

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